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# ULTRASONIC TEMPERATURE MEASURING DEVICE

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L. C. Lynnworth and E. H. Carnevale

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Contract NAS3-7981

PARAMETRICS, INC.

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ABSTRACT

Acoustic tests with the rhenium sensor show that if a metal sheath is to be used to retard carbon penetration into the sensor it is necessary to provide acoustic isolation between the sensor and the sheath. It is found that hafnium oxide and beryllium oxide beading of the sensor is useful if the sensor is left free to expand axially. The tests also show that the bare rhenium sensor can survive in a carbon atmosphere up to temperatures of at least $\sim 4500^{\circ}R$ for periods of about one hour despite embrittlement.

Acoustic attenuation data were obtained for a number of metals and alloys. The data show that the attenuation varies slightly with temperatures up to some particular temperature and then increases rapidly (approximately exponentially) with temperature above this temperature. The temperature at which this rapid increase in attenuation occurs is highest for tungsten. Tungsten is therefore a favorable choice for at least one of the lead-in wires to be used for future acoustic tests in the WANL oven.

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## I. INTRODUCTION

Earlier in this program, after studying and testing various refractory wires, rhenium sensors were selected and then tested up to and beyond $5000^{\circ}R$ in vacuum, and performed satisfactorily. Comparisons of irradiated and control rhenium wires showed no significant changes in the velocity/temperature characteristic. Instrumentation to automatically measure the transit time in the sensor has been designed, built and tested, and meets or exceeds specifications. The sensor itself has been reduced in size from ~0.040" x 5" to ~0.020" x 2". The principal remaining problem is to study sensor operation in a high temperature, high pressure graphite/hydrogen environment.

Because bare rhenium is known to become embrittled after high temperature exposure to graphite, even though there is no carbide formation, recent work has been devoted to testing available thermocouple sheaths with respect to their ability to retard carbon penetration into the rhenium sensor.

## II. ACOUSTIC ISOLATION OF THE SENSOR

Sheaths consisting of W-25% Re clad with pure tungsten to serve as carbon diffusion barrier have been acoustically tested with rhenium sensors at room temperature. Figure 1(d) shows that the end echo in a 14" rhenium sensor is seriously attenuated when the end of the sensor makes contact with the metal sheath. Figure 1(c) shows that when the same sensor is acoustically isolated from the sheath there is no attenuation. With a rhenium sensor in tight physical contact with beryllia beads the echoes are attenuated (Figure 2); additional tests show that a rhenium sensor with loose fitting hafnium oxide or beryllium oxide beads performs substantially the same as bare rhenium sensors provided the sensor is free to expand axially.

## III. THE RHENIUM SENSOR IN A CARBON ATMOSPHERE

Sound velocities were measured in two-inch bare rhenium sensors in direct physical contact with graphite felt (see Figure 3) up to temperatures of at least $4500^{\circ}R$. The sensors survived at $4500^{\circ}R$ for one hour and approximately $5000^{\circ}R$ for 15 minutes. On cooling to room temperature from $4500^{\circ}R$, the room temperature velocity was observed to be reproducible. These sensors became brittle as expected, but remained intact unless they were disturbed mechanically; breakage usually occurred at the weld joints or at right angle reflection bends. There was some attenuation (Figure 4) at high temperatures,* but data were obtained up to about $5000^{\circ}R$ (see oscillograms, Figure 5). Below $\sim 4000^{\circ}R$ the attenuation was negligible, and so no data points are shown in Figure 4 for this range.

## IV. ATTENUATION IN A THIN WIRE

We have observed that the attenuation coefficient $\alpha$ generally tends to increase with temperature. Since it is desirable to select the lead-in wire which will be least attenuating, the attenuation coefficient was determined as a function of temperature for a series of metals and alloys. It is known, however, that tungsten, although one of the least attenuating, becomes embrittled once it is heated above its recrystallization temperature, while tungsten alloyed with $\sim 26\%$ rhenium does not become so brittle. The choice of a lead-in

*Temperatures were estimated from change in transit time, using previous data for pure rhenium. The rhenium data were obtained by heating wires in the Abar oven, and recording transit times as a function of temperatures measured with a Leeds & Northrop disappearing filament pyrometer (see NASA CR-72517, January 1967).

wire is based on such considerations. Another factor to be considered is the possible changes in the attenuation coefficient as a result of appropriate preparation of the wire, such as annealing.

The attenuation coefficient $\alpha$ can be computed from the echo amplitudes $A_o$ and $A_1$ arising at the beginning and end of the sensor, respectively. The acoustic pressure amplitude A is given by

$$A = A_o e^{-\alpha x}$$

where x is the round trip distance between the beginning of the sensor and the point where A is reflected in a pulse-echo test. When A is reflected at the end of the sensor, we have

$$A_1 = A_o e^{-\alpha x}$$

(Experimentally, it is often convenient to adjust $A_1$ to equal $A_o$ at room temperature. This is equivalent to assuming $\alpha = 0$ at room temperature.) Now, taking the natural log in the above expression,

$$\alpha = \frac{1}{x} \ln \frac{A_o}{A_1} \quad \text{nepers/unit length}$$

$$= \frac{8.686}{x} \ln \frac{A_o}{A_1} \quad \text{db/unit length}$$

or

$$\alpha = \frac{20}{x} \log_{10} \frac{A_o}{A_1} \quad \text{db/unit length.}$$

Attenuation data in the range ~1 to 10 db/ft were obtained at ~250 kHz as a function of temperature for the following sensor materials:

tungsten, molybdenum, rhenium, and tungsten alloys containing 5 and 26% rhenium. Specimen lengths were increased to between one and two feet to increase the accuracy of the measurements. The attenuation coefficients were computed using the method indicated above. The results are shown in Figure 6 for the temperature range $\sim 2700^{\circ}R$ to $\sim 4500^{\circ}R$, i.e., for temperatures at which $\alpha$ exceeds 1 db/ft. In each case measurements were carried up to the temperatures at which the echo amplitudes decreased to values below 2 volts, or the signal-to-noise ratio decreased to values below 1.

It can be seen that tungsten maintains a relatively low attenuation up to $\sim 4500^{\circ}R$. Tungsten also survived the temperature cycling during repeated runs and will therefore probably be used as one of the lead-in wires in future WANL oven tests.

Once the temperature dependence of the attenuation coefficient has been established it is possible to predict the maximum working length and temperature of a given sensor material according to Figure 6. For example, if the maximum attenuation in a rhenium sensor is to be of the order of 1 db, but the maximum working temperature is to be at least $4500^{\circ}R$, it may be deduced from Figure 6 that the corresponding maximum length of the rhenium sensor should be about 2 in. This is in agreement with earlier work with a 2 in. rhenium sensor. The data shown in Figure 6 indicate that the attenuation bears the following approximate relation to the temperature at $T > 2700^{\circ}R$ and $f \sim 250$ kHz:

$$\alpha \sim e^{\beta T}$$

where $\beta$ is the temperature coefficient of attenuation.

## V. FUTURE WORK

In the future, rhenium sensors will be acoustically tested in the WANL oven. The tests will be conducted at both high and low frequencies and are planned to include bare and sheathed runs as follows:

1. Bare assembly:
    - (a) tungsten lead-in welded to rhenium sensor
    - (b) rhenium lead-in and rhenium sensor formed with a $45^{o}$ kink in the rhenium wire
2. Sheathed assembly:
    - (a) tungsten lead-in welded to rhenium sensor
    - (b) repeat of 2(a) with the second of two sheaths provided.

(a)

(b)

(c)

(d)

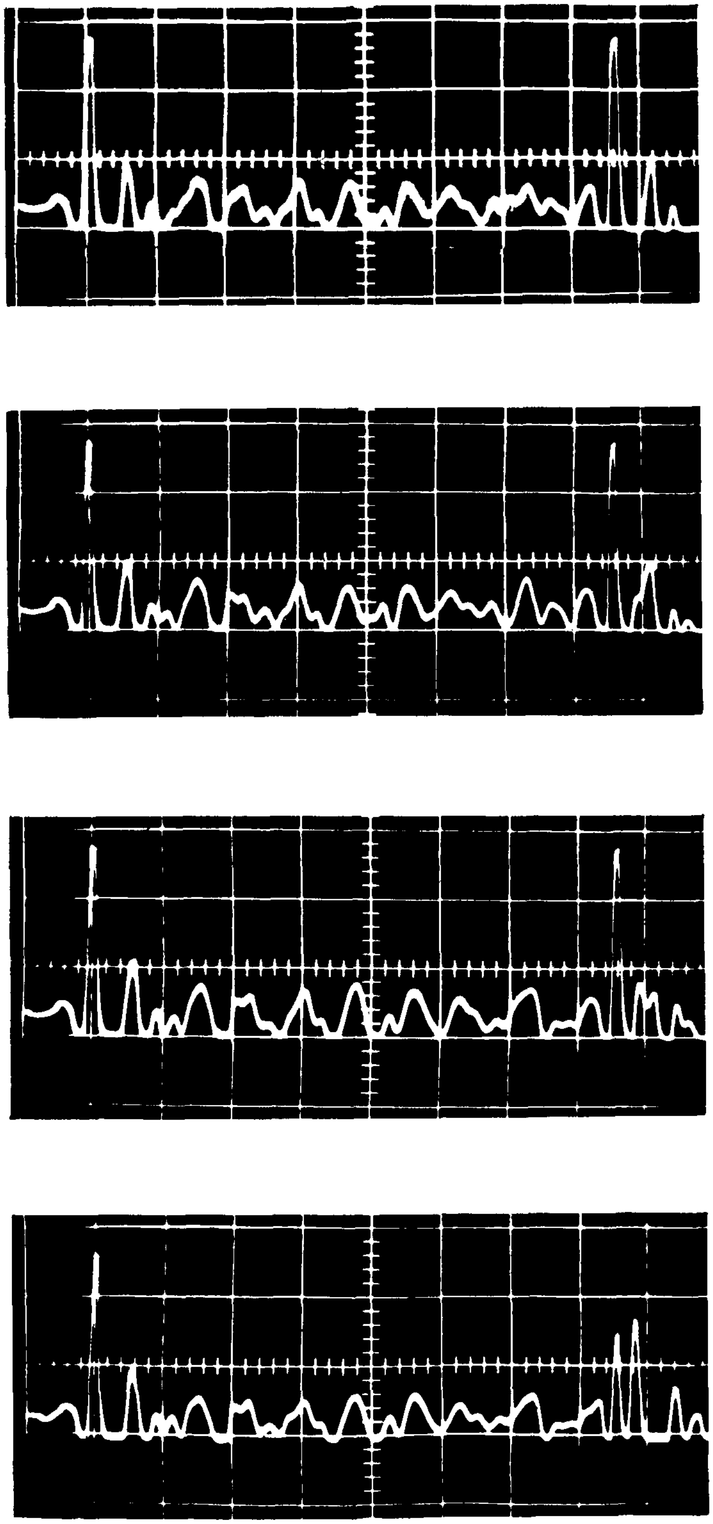


FIGURE 1. (a) sensor bare; (b) sensor in ceramic tubes; (c) sensor in ceramic tubes within W/Re thermowell; (d) same as (c) but with sensor touching thermowell bottom. Sensor, 14" long. Sweep, 20 μsec/cm.

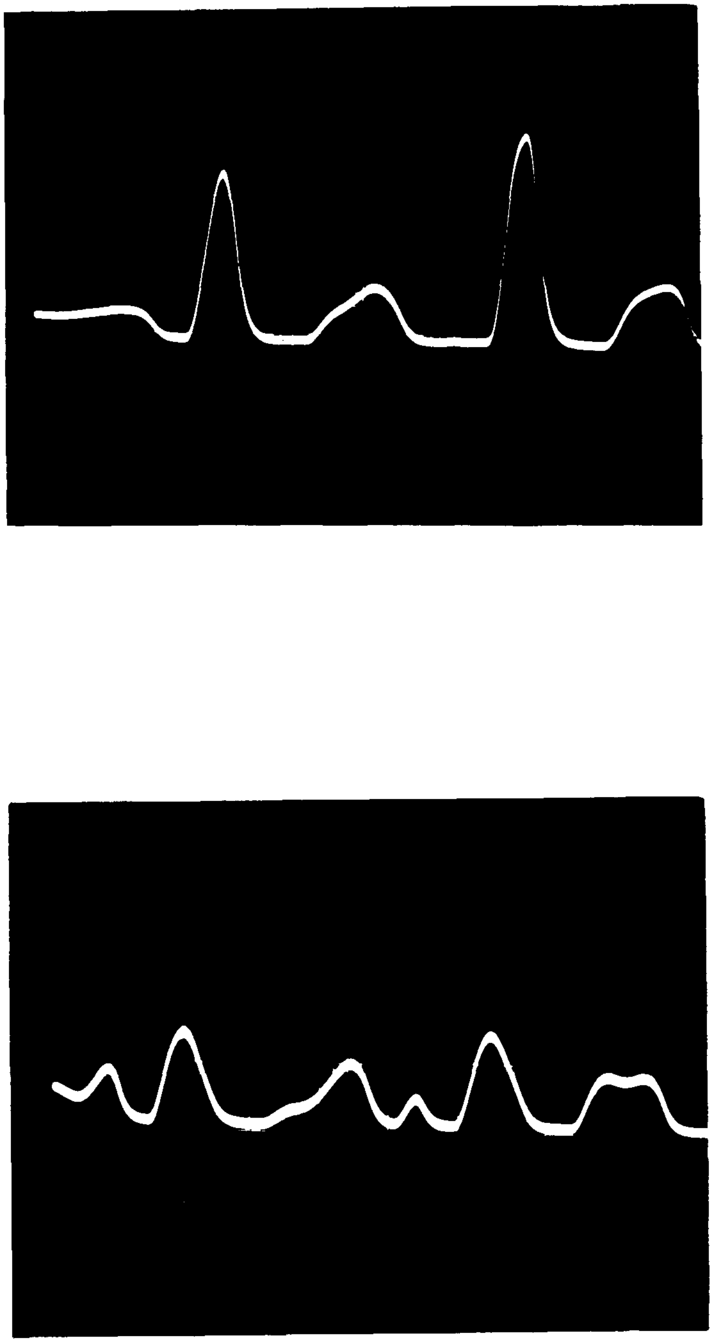


FIGURE 2. (top) sensor bare; (bottom) lead-in of 0.030" dia. Re in close contact with beryllia tubes, resulting in attenuation of sensor echoes. Sensor, 2" long. Sweep, 5 μsec/cm.

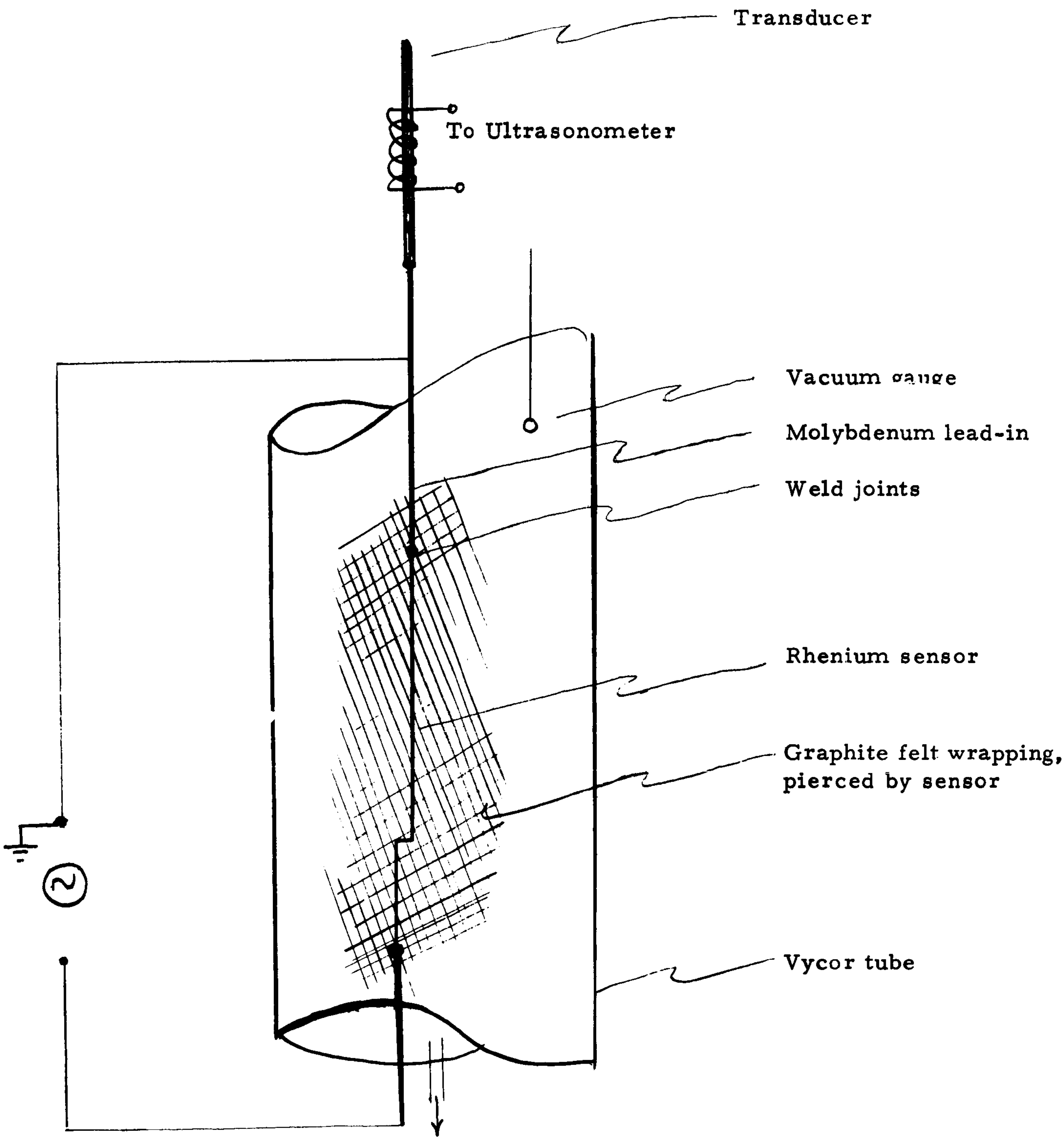



Figure 3. Apparatus to test survival of rhenium sensor in graphite

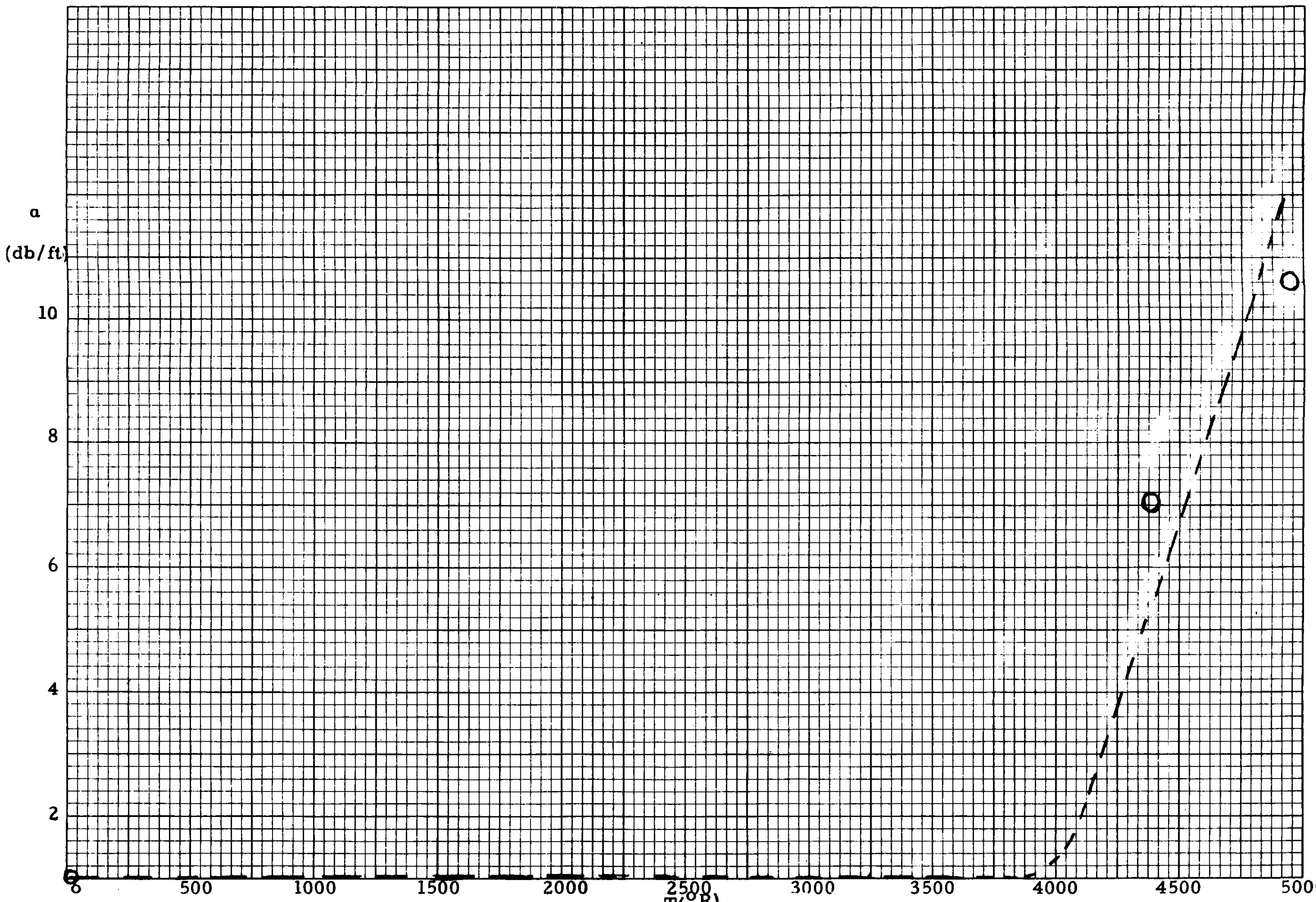
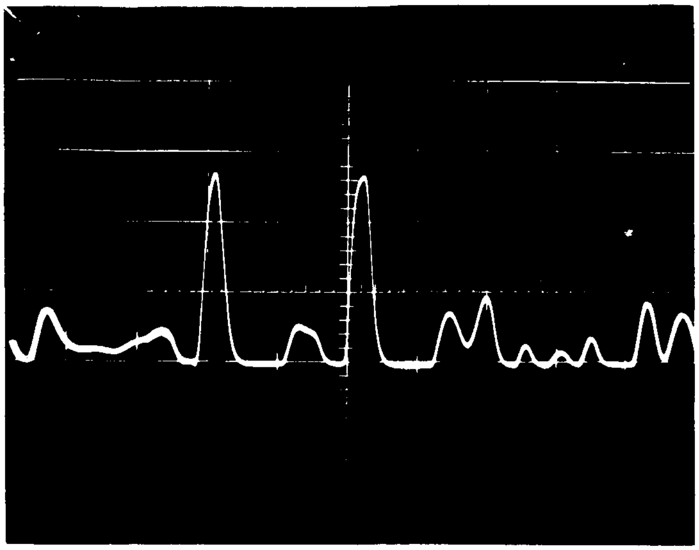
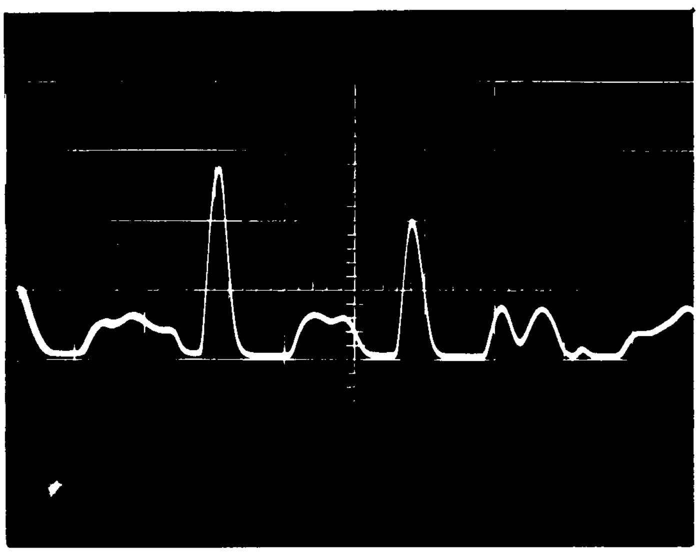



**Figure 4.** Attenuation, α, at high temperatures, for a bare rhenium sensor in graphite, f ~ 250 kHz.



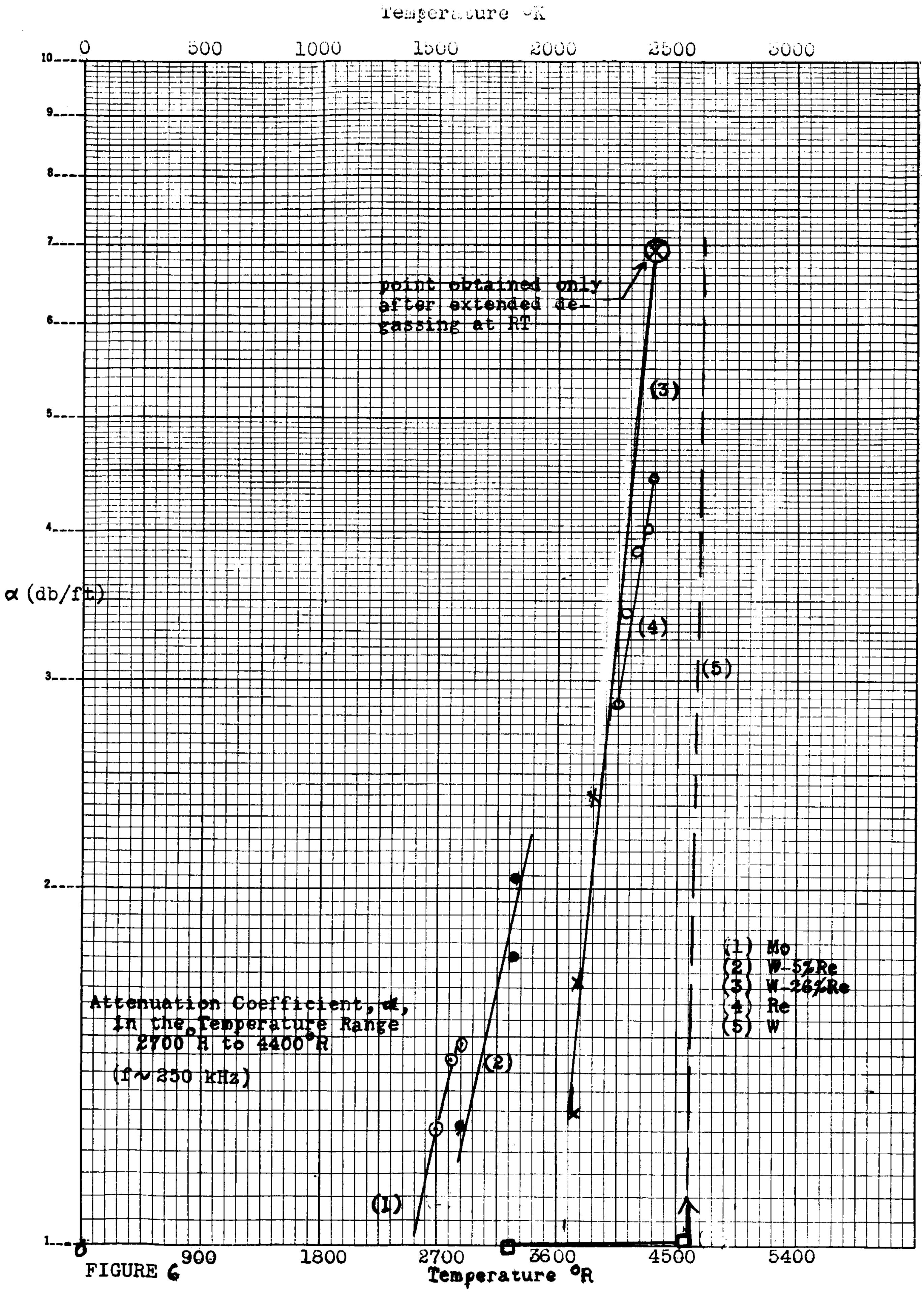
(a) $V/V_o = 1$; $T \approx 530^oR$



(b) $V/V_o = 0.762$; $T \approx 4400^oR$

(c) $V/V_o = 0.706$; $T \approx 5000^oR$

Figure 5. Oscillograms showing attenuation in bare rhenium sensor in graphite felt.



Temperature °K
0
500
1000
1500
2000
2500
3000
10
9
8
7
6
5
4
3
2
1
α (db/ft)
point obtained only after extended de-gassing at RT
(3)
(4)
(5)
(2)
(1)
(1) Mo
(2) W-5%Re
(3) W-26%Re
(4) Re
(5) W
Attenuation Coefficient, α, in the Temperature Range 2700°R to 4400°R
(f ~ 250 kHz)
0
900
1800
2700
3600
4500
5400
Temperature °R


FIGURE 6